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(54) Optical radiation devices.

(57) A device, particularly an antenna device, for emitting a beam of optical radiation to irradiate a remote target area. The device includes an optical source (10) having a limited wavelength band, and a hologram pattern (14) positioned in the path of a light beam originating from the source, the pattern being selected to produce a composite beam (20) having a predetermined shape or far field pattern conforming to the target area and/or a predetermined distribution of light intensity in the target area. Where the optical source is a point source, the hologram pattern (14) selectively retards the phase of respective components of the incident wavefront to produce a composite beam having a far field pattern that precludes focusing of the beam into a single small spot. The device has particular application in a telecommunication system wherein a data signal is transmitted through free space by an optical beam, at least one characteristic of the beam being controlled by the hologram pattern in the path of the beam.

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This invention relates to a device, particularly an antenna device, for emitting a beam of optical radiation to irradiate a remote target area.

It is well known that a laser can be used to produce a sharply defined and intense beam of infra-red radiation, and a conventional lens can spread this beam out over a target area. Other point sources, such as infra-red light emitting diodes, can also produce sharply defined directional beams and are used, for example, to illuminate target areas in remote television and video control apparatus.

In general, however, when irradiating a remote target area with optical radiation, much of the radiation from the original source inevitably falls outside the target area and is wasted. Moreover, although the angle of divergence of a beam can be controlled, there is little or no control over the intensity distribution within the beam or the shape of the beam envelope. It is particularly difficult to illuminate a square, rectangular or other non-circular target area with a uniform intensity beam. In an optical free space communication system where the radiation is carrying a telecommunication signal, the spillage of energy can also result in inadvertent detection of the signal by a detector outside the target area.

A further problem arises if the source is a point source. In this case there is a risk that the infra-red radiation could be inadvertently focused by a lens, for example a binocular lens, on to the skin, or worse still, the retina, and cause permanent damage. This latter problem is particularly acute at high power levels and restricts the possible use of high power sources, including both light emitting diode (LED) and laser emitters, in an optical free space communication system, or in any application where optical radiation is emitted into a populated area.

The present invention provides a device, particularly an antenna device, for emitting a beam of optical radiation to irradiate a remote target area, wherein the device includes an optical source having a limited wavelength band, and a hologram pattern is positioned in the path of a light beam originating from the source. According to one aspect of the invention, the pattern is selected to produce a composite beam having a predetermined far field shape or pattern conforming to the target area and/or a predetermined distribution of intensity over the target area. According to a second aspect of the invention, where the optical source is a point source, the hologram pattern selectively retards the phase of respective components of the incident wavefront to produce a composite beam having a far field pattern that precludes focusing of the beam into a single small spot.

By a limited wavelength band we mean a band having upper and lower limits, particularly, where the upper limit is less than twice the lower limit. In addition, the term "optical" is intended to refer not only to that part of the electromagnetic spectrum which is generally known as the visible region but also the infra-red and ultraviolet regions at each end of the visible region.

The hologram pattern can be any diffractive structure designed to produce a predetermined distribution of intensity in the target area from a single incident wavefront. The distance of the target area from the optical source can be anything from a few metres up to several kilometres.

According to a third aspect of the invention there is provided a telecommunication system wherein a data signal is transmitted through free space by an optical beam, characterised in that at least one characteristic of the beam is controlled by a hologram pattern in the path of the beam. Particular characteristics which might be controlled are the intensity distribution, the far field shape, and/or the angle of divergence of the beam.

To accommodate the wavefront of a diverging beam, the hologram pattern is conveniently repeated to form a periodic repeat pattern of a single cell, each cell producing an array of beams. The repeating pattern breaks up the distribution of intensity in the target area into a pattern of individual spots, but these spots can merge into one another if the incident beam is diverging. In this case the dimensions of each cell control the angular spread of the array of beams, and the smaller the cell the greater is the angular spread.

The hologram pattern in each cell preferably imposes a pattern on the incident wavefront by selectively retarding the phase of the incident wavefront. In this case, the resulting array of beams emerging from each cell of the hologram cannot be focused into a single small spot, and the hologram pattern has the same effect as a diffusing screen or microlens array while retaining precise control over the shape and direction of the composite beam. Accordingly, the device is not only safe to use, even at high power levels, but it has the ability to direct light accurately into a particular target area of a given shape while also controlling (if required) the intensity distribution across the area.

The potential applications of the device are therefore considerable.

Where the device is an antenna device, one such application would be in an optical free space communication system since the device allows safe transmission of greatly increased amounts of power while retaining the advantages of a laser or LED source. In this case, the target area might be precisely defined or more broadly defined. For

example, it might be a single floor in an office building, an individual window or windows in a building or block of buildings, or a single building or row or block of buildings in a street. Advantageously, the antenna could be positioned at the top of a pole, or a series of poles, in a street as in the present telegraph system.

Other possible applications where eye safety rather than beam control is the prime consideration would be in television/video remote controllers where the light should at least point in the general direction of the detector on the TV or video recorder, car brake lights where the light should point in a generally backwards direction and in museums or art galleries where a signal carrying information relating to a particular picture or museum item could be directed by an infra-red beam into an area immediately in front of the picture or item for detection by the wearer of a personal headset.

If the hologram pattern is being used primarily to inhibit focusing of the light, the far field width of the light, or the spread of the beam, may not necessarily be any greater than without the hologram. In this case, the only effect of the hologram is to make the light impossible to focus, without necessarily changing the shape or direction of the beam. The size of the individual cells in a repeating pattern of cells forming the pattern might then be larger than when the hologram is being used to direct the beam into a particular defined target area.

By way of example only, some embodiments of the invention are illustrated in the accompanying drawings in which:

Fig. 1 is a diagrammatic sketch of an optical radiation device embodying the invention;

Fig. 2 illustrates three possible hologram phase patterns for use in the device of Fig. 1 to produce three differently shaped far field patterns;

Fig. 3 illustrates diagrammatically an arrangement for illuminating a target area consisting of four juxtaposed square cells using four of the radiation devices in Fig. 1 grouped together;

Fig. 4 illustrates diagrammatically an arrangement using the device of Fig. 1 as an antenna device for illuminating a single building in a row of buildings;

Fig. 5 is similar to Fig. 4 and shows an arrangement for illuminating a row of buildings in a street;

Fig. 6 shows an arrangement for illuminating selected houses in a street; and

Fig. 7 shows an arrangement having multiple sources at different wavelengths for respectively illuminating three adjacent cells in the target area.

Referring first to Fig. 1, the radiation emitter includes a laser diode source 10 enclosed in a housing 11. The front of the housing is open or transparent such that light from the source 10 is incident on a hologram 12 positioned over the front. The housing 11 may optionally include at least one lens 13 to either expand or at least partially collimate the beam before it strikes the hologram.

The hologram 12 consists of a transparent plate 18 on which a surface relief interference pattern 14 has been embossed. The pattern itself is protected by a further transparent screen 15.

The pattern 14 is a computer-generated interference pattern derived from a mathematical model and conveniently consists of a repeating cell or unit pattern 22. A detailed report on the production of such patterns can be found in a paper entitled "Efficient optical elements to generate intensity weighted spot arrays: design and fabrication" (Applied Optics Vol. 30, No 19 pp 2685-2691).

Each cell pattern 22 is designed to produce an array of beams which together form a composite beam having a predetermined shape, i.e. the interference pattern 14 in each cell imposes a pattern on the incident wavefront by selectively retarding the phase of the incident light, and produces a predetermined distribution of light intensity in the target area. For optimum performance, the hologram 12 should be designed to put as much as possible of the incident light into the target area with as little as possible of the light being scattered into higher angles outside this area.

The pattern 22 is derived from an algorithm which initially sets the required far field pattern, compares it with a random pattern of pixels, and assesses the closeness of the fit. Each pixel is then examined in turn to determine where a change of phase is required to produce a closer fit. The process is repeated many times until a sufficiently close fit is achieved.

Three possible examples of a single cell in the interference pattern 14 are shown in Fig. 2 together with the resulting light distribution. As can be seen, the cell 22a produces a circular far field intensity pattern 30a, the cell 22b produces a square pattern 30b, and the cell 22c produces a rectangular pattern 30c. The black areas in each cell 22 denote an area with a phase retardance of half a wavelength compared to the white areas, and the physical size of the cell determines the angular spread of the beams - the smaller the size of the cell, the greater is the angular spread. The phase of the light across the far field pattern 30 is extremely complex and makes the light impossible to refocus.

Fig. 2 illustrates the far field pattern of light which would be obtained if a single cell 22 were illuminated by a coherent parallel light beam of uniform intensity. The pattern represents the intensity of the Fourier transform from one single, iso-

lated cell of the phase hologram pattern 14, with about 75% of the light energy falling in the bright area and the remaining 25% outside. In practice, by repeating the cell pattern 22 over a large two-dimensional array, the Fourier transform becomes an array of spots within the respective bright shaped areas shown in Fig. 2 for each of the cell patterns 22a, 22b, 22c.

This large two-dimensional array of cells forms the pattern 14 of Fig. 1. When illuminated by a diverging beam (rather than a parallel beam) the size of the spots is increased although the spacing between them is unaffected. If the divergence of the beam is sufficiently large (or the spacing between the spots is sufficiently small), the spots may merge into one another to form a continuous intensity distribution.

The pattern 22 is preferably a phase-only pattern, i.e. it does not block any light but just changes the phase. The phase-only pattern is produced, for example, by reactive-ion etching through a black/white pattern mask into quartz glass, or by etching through a photo-resist mask directly written by electron-beam lithography. Once the pattern has been recorded on a master plate, duplicate copies are easily reproduced.

The pattern 14 could alternatively be formed as a reflection hologram in which case the etch depth would be selected to retard the phase by a quarter wavelength since the light would then pass in both directions and the phase would be shifted twice.

The distance of the target area from the optical source 10 can vary from a few metres up to several kilometres.

Figs. 3-7 illustrate various applications of the device shown in Fig. 1 when used as an antenna device, the same reference numerals being used to denote like parts. Each of these applications is in an optical free space communication system where the light is carrying a telecommunication signal, such as a television signal.

In Fig. 3 four laser diode sources 10a, 10b, 10c, 10d are used with respective holograms 12a, 12b, 12c 12d to illuminate four juxtaposed target cells 23a, 23b, 23c, 23d.

In Fig. 4 the hologram 12 has an interference pattern 14 designed to produce a rectangular shaped vertical beam 24 which is used to illuminate a single building 25d in a row of buildings 25a, 25b, 25c and 25d.

In Fig. 5 the hologram pattern 14 again produces a rectangular shaped beam but in this case the beam 20 is horizontal rather than vertical such that it illuminates a row of houses in a street.

In Fig. 6 the holographic pattern 14 produces a combination of a rectangular shaped beam and a square shaped beam to pick out individual target areas and hence illuminate both a group of three houses 26 in a street as well as a single individual house 27 in the street. The same principle could be used, for example, to illuminate individual offices in a building.

In Fig. 7 multiple laser diode sources 10a, 10b and 10c direct light through a single hologram 12. Each source has a different characteristic wavelength such that the hologram pattern separates the light into adjacent cells 29a, 29b, 29c corresponding to the different frequencies. In this case the hologram 12 could be a simple diffraction grating since the deflection angle of a diffraction grating is proportional to the wavelength. This arrangement is particularly useful where wavelength multiplexing (WDM) is used for separate data channels. As well as using such a grating as a common element to separate into adjacent cells the output from a number of sources 10 emitting different wavelengths, the grating could be used to gather together on to a single detector the return light at different wavelengths from separate cells, or to separate into different detectors light at several different wavelengths all emitted from the same cell or spacial location.

Another possibility would be to illuminate the hologram 12 using a single source 10 and then sweep the frequency of the source such that the beam emerging from the hologram scans the target area.

The use of a hologram to control the shape of the beam in each of the above applications has an important additional advantage. If the interference pattern 14 is designed so that the beams in each array of beams from each cell of the pattern are out of phase with one another, the resulting composite beam from the hologram cannot be focused into a single small spot. This means that greatly increased amounts of power can be transmitted without risk of eye or skin damage.

For example, referring again to Fig. 1, if a converging lens 16 (such as an eye lens) is positioned in the path of the composite beam 20 emerging from the hologram 12, a two dimensional array of images of the source 10 would be formed in the back focal plane 19 of the lens. The distribution of intensity in these images is determined by the individual cell pattern 22. The images would be separated by a distant $(D\lambda)/L$ where λ is the wavelength of the source 10, D the working distance of the focal plane from the lens, and L the width of a single cell or unit in the repeating hologram pattern 14.

If the source 10 emits a narrow range of wavelengths, the images in the back focal plane 19 would be smudged.

To a good approximation, the image in the back focal plane 19 is given by the Fourier Transform of the phase transmittance of the hologram 12

times a phase factor determined by the distance of the lens 16 from the hologram. If the Fourier Transform is such as to produce an extended image in the back focal plane 19, the light will appear to the viewer as if it came from an extended object. The extent of the effective object is given by the extent of the image divided by the magnification of the lens arrangement.

If the hologram 12 produces a uniform N x N square array of beams, the image in the back focal plane 19 (i.e. the target area covered by the array) has a size N $(D\lambda)/L$. If P is the incident power collected by the lens, and the working distance D is 10mm (which is the distance of the retina from the eye lens at close focus), the power density in the retina is given by $P \times (L^2/\lambda^2/N^2) \times 10^4 W/m^2$. The power density can therefore be controlled by the hologram pattern - the smaller the unit cell size L, or the greater the number of beams generated, the lower will be the power density. It is possible to achieve a reduction of 2500 times in the maximum power density in the retina compared with a system transmitting the same total power without a hologram.

The limit to the effectiveness of the hologram 12 in diffusing the light is the effective bandwidth of the source 10. In addition, a small phase error in the hologram gives rise to a small portion of the light being undeflected by the hologram. This portion can be focused by the lens 16. The phase error can be caused by either an error in the depth of the pattern in the surface, a difference in the source wavelength from the design value, or lithographic errors in the processing. Its effect is small, however; - a 10% error in the profile depth or the source wavelength leads to less than 1% of the power being undeflected and would therefore still allow a 100 fold improvement in the amount of power that can be safely emitted.

Claims

1. A device, particularly an antenna device, for emitting a beam of optical radiation to irradiate a remote target area, the device including an optical source (10) having a limited wavelength band, and characterised by a hologram pattern (14, 22) positioned in the path of a light beam originating from the source, the pattern (14, 32) being selected to produce a composite beam (20) having a predetermined shape or far field pattern (30) conforming to the target area.

2. A device, particularly an antenna device, for emitting a beam of optical radiation to irradiate a remote target area, the device including an optical source (10) having a limited wavelength band, and characterised by a hologram pattern (14, 22) positioned in the path of a light beam originating from the source, the pattern (14, 22) being selected to produce a predetermined distribution of light intensity (30) in the target area.

3. A device for emitting a beam of optical radiation to irradiate a remote target area, the device including an optical point source (10) having a limited wavelength band, and characterised by a hologram pattern (14, 22) positioned in the path of a light beam originating from the source, the pattern (14, 22) selectively retarding the phase of respective components of the incident wavefront to produce a composite beam (20) having a far field pattern that precludes focusing of the beam (20) into a single small spot.

4. A device according to claim 1 or claim 2 in which the hologram pattern (14, 22) selectively retards the phase of respective components of the incident wavefront such that the composite beam (20) has a far field pattern that precludes focusing of the beam (20) into a single small spot.

5. A device according to any one of the preceding claims in which the hologram pattern (14, 22) changes only the phase of the incident light.

6. A device according to any one of the preceding claims in which the hologram pattern (14, 22) comprises a surface relief pattern on a transparent substrate (18).

7. A device according to any one of the preceding claims in which the hologram pattern (14) is a repeating pattern of a single cell (22).

8. A device according to any one of the preceding claims including a plurality of the optical sources (10a, 10b, 10c) having different wavelength bands, and wherein the hologram pattern (14, 22) receives light from each of the sources and separates the incident light into respective composite beams (20) corresponding to the different wavelength bands and each illuminating a respective target area.

9. A device according to any one of the claims 1-7 further comprising means for sweeping the frequency of the source (10) through a continuous range of frequencies whereby the composite beam (20) emerging from the hologram pattern scans the target area.

10. An optical free space communication system comprising a device according to any one of the preceding claims wherein the light carries a telecommunication signal and the device directs the composite beam (20) through free space to the target area.

11. A telecommunication system wherein a data signal is transmitted through free space by an optical beam, characterised in that at least one characteristic of the beam (20) is controlled by a hologram pattern (14, 22) in the path of the beam.

12. A system according to claim 11 in which the hologram pattern (14, 22) controls the far field shape and/or direction of the beam.

13. A system according to claim 11 or claim 12 in which the beam (20) is a composite beam and the hologram pattern (14, 22) controls the relative phase of the beam components.

14. A system according to claim 13 in which the beam components are out of phase with one another such that the composite beam (20) cannot be focused into a single small spot.

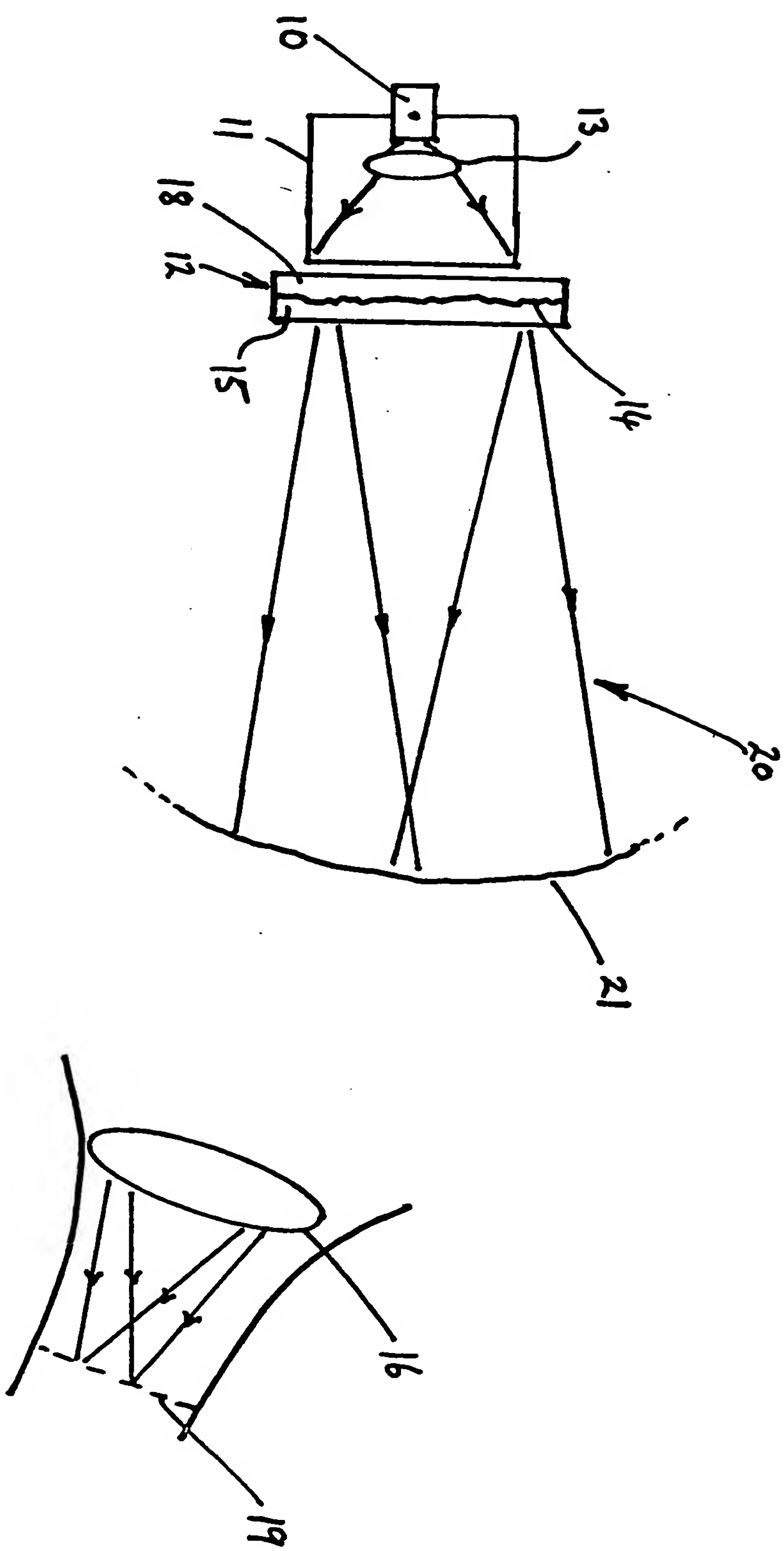


Fig 1

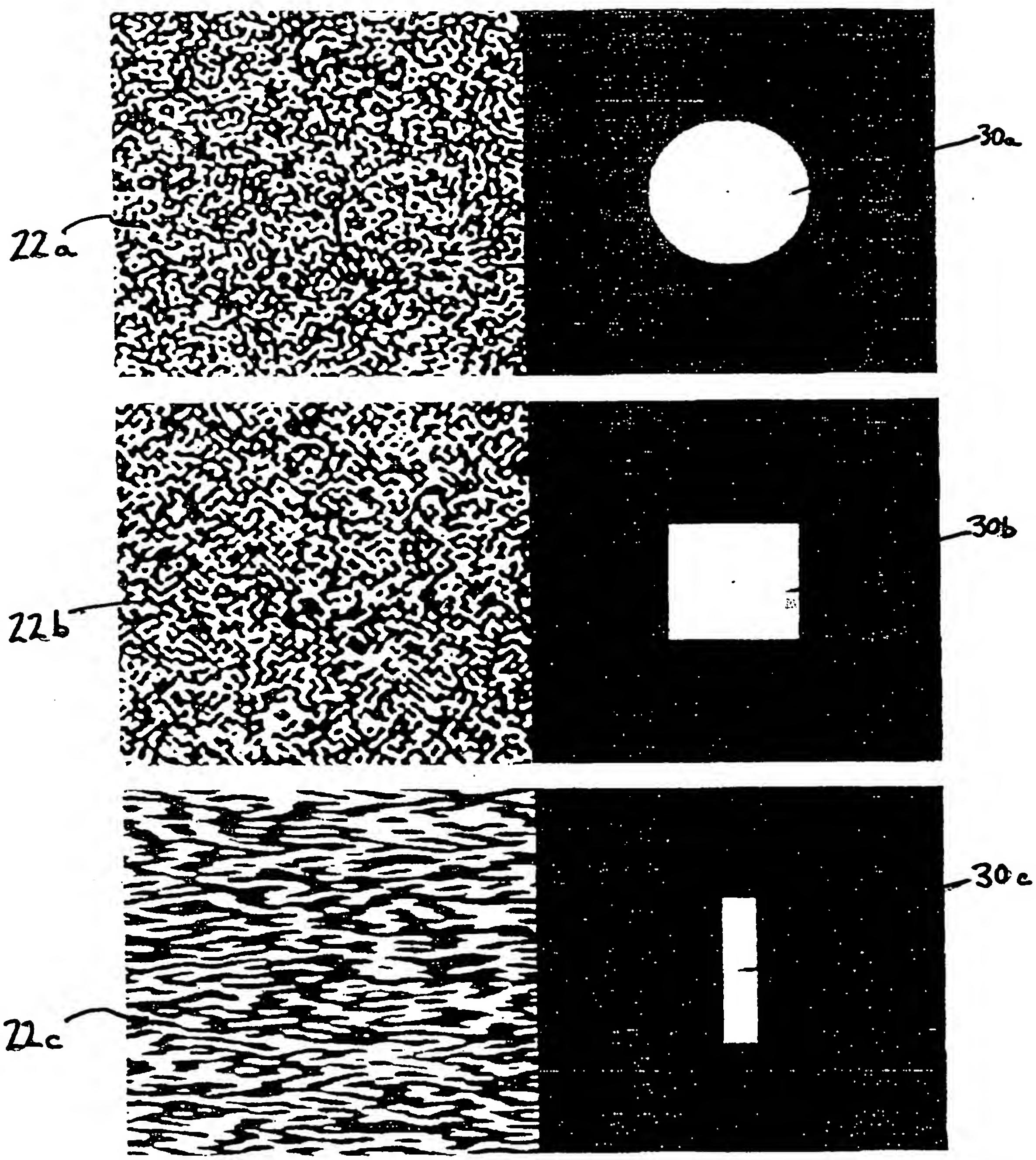


Fig. 2

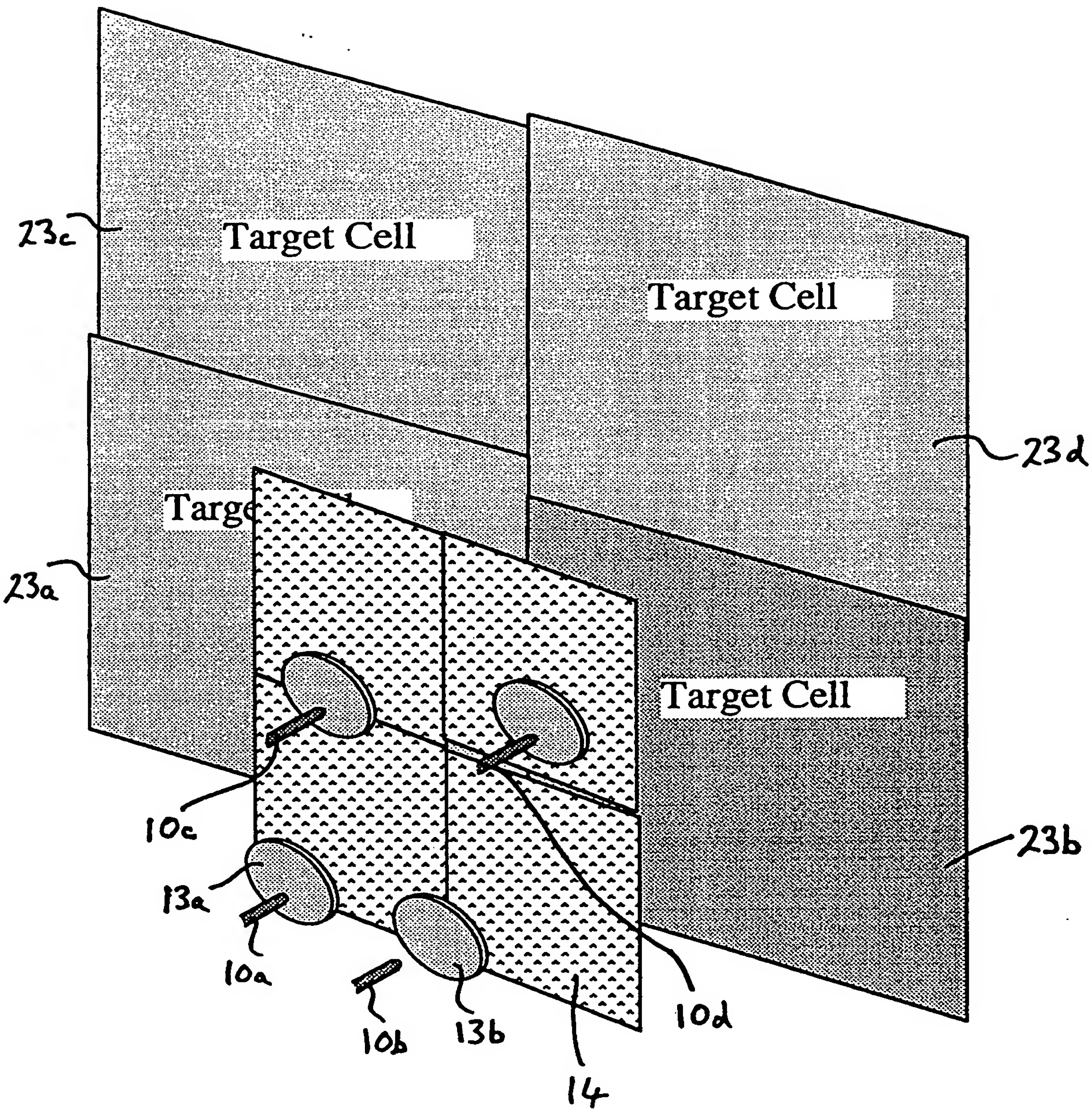

23c
Target Cell
Target Cell
Targe
23a
23d
Target Cell
10c
13a
10a
10b
13b
14
10d
23b

Fig 3

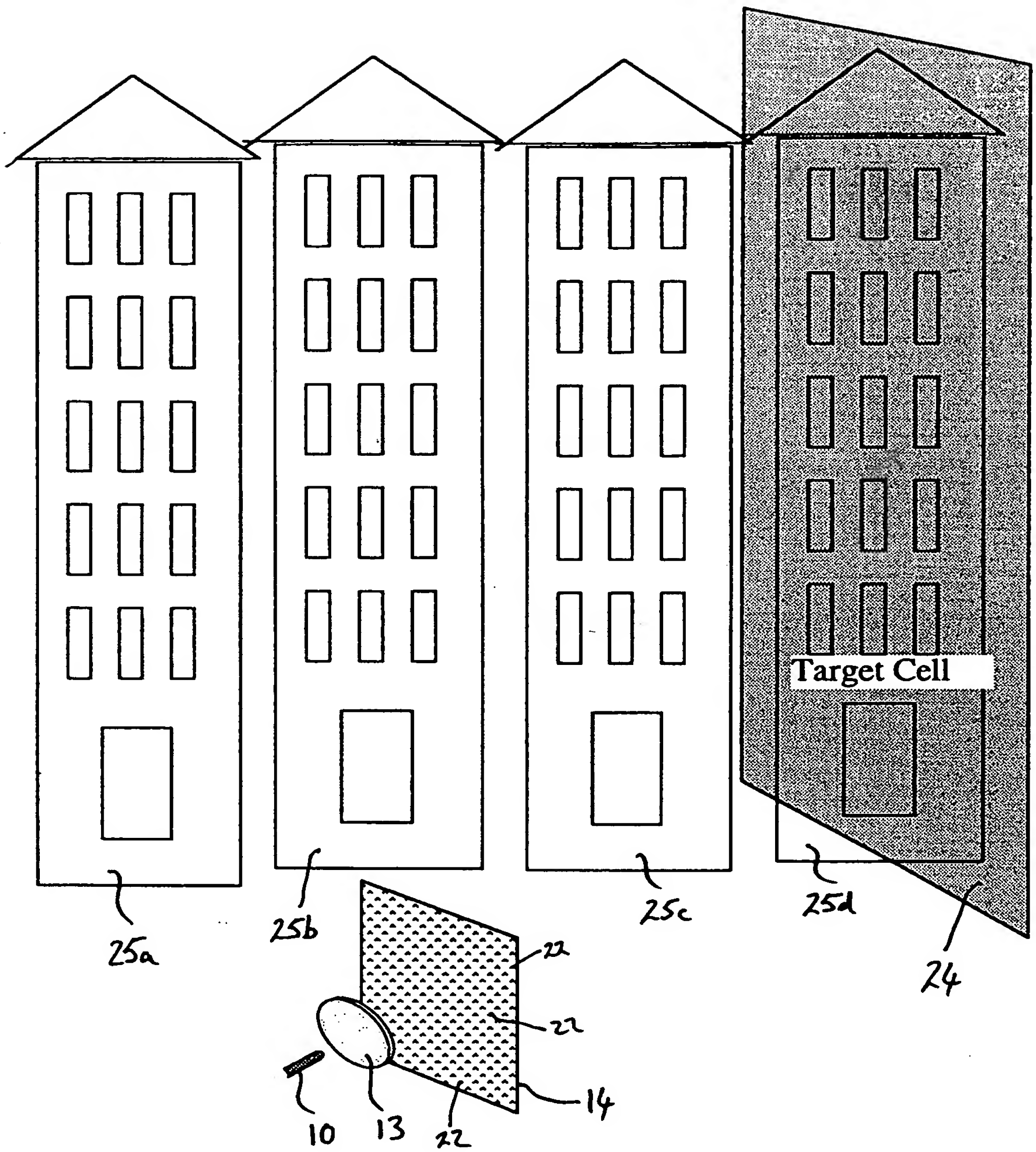
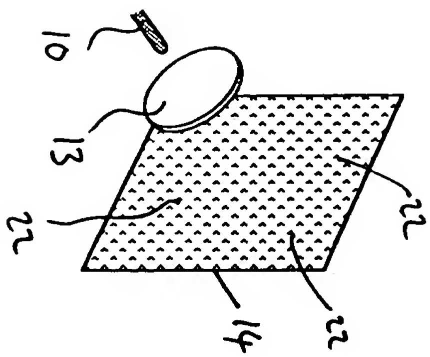


Fig 4



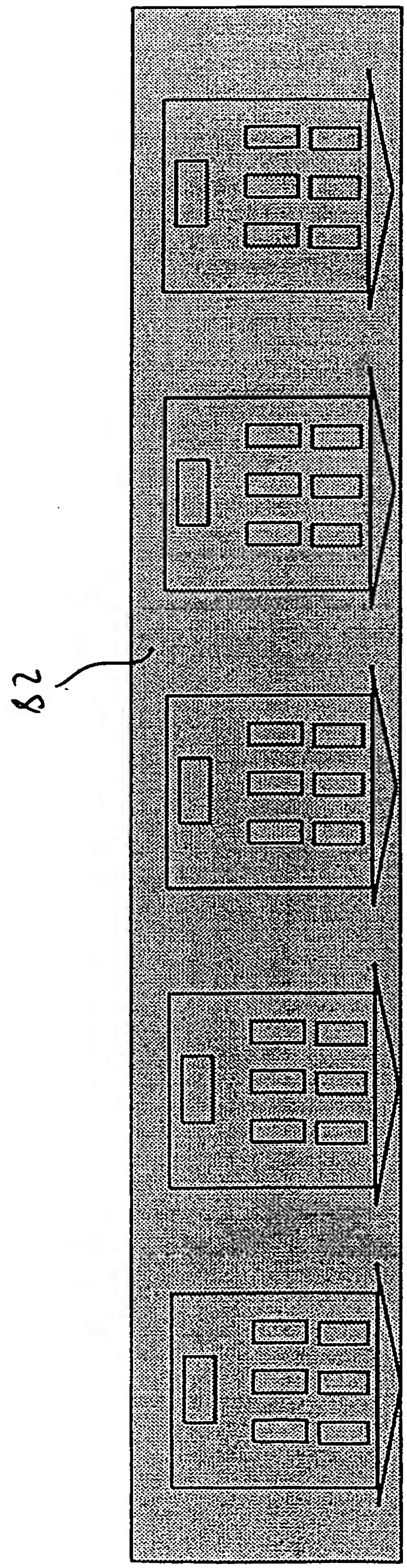


Fig 5

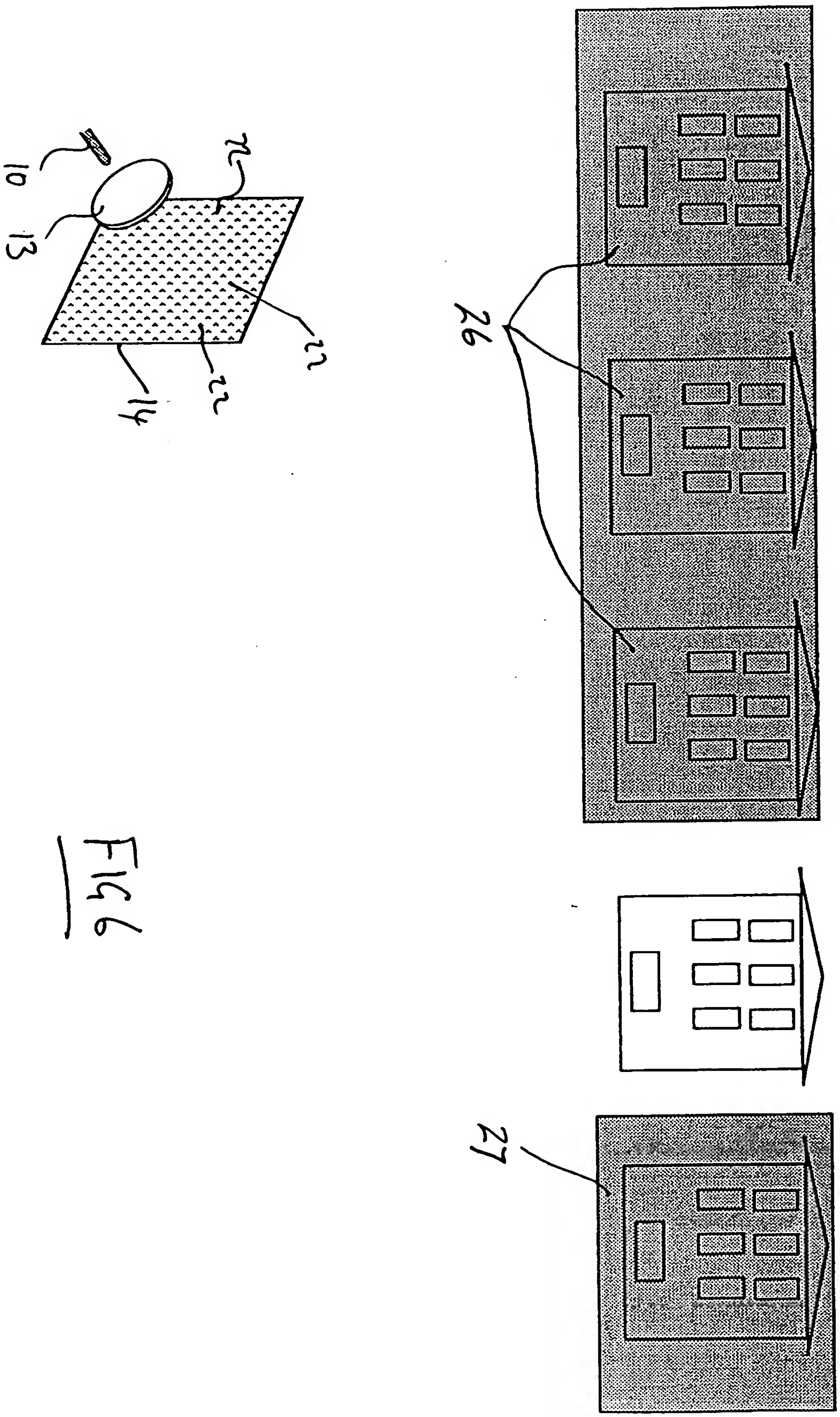


FIG 6

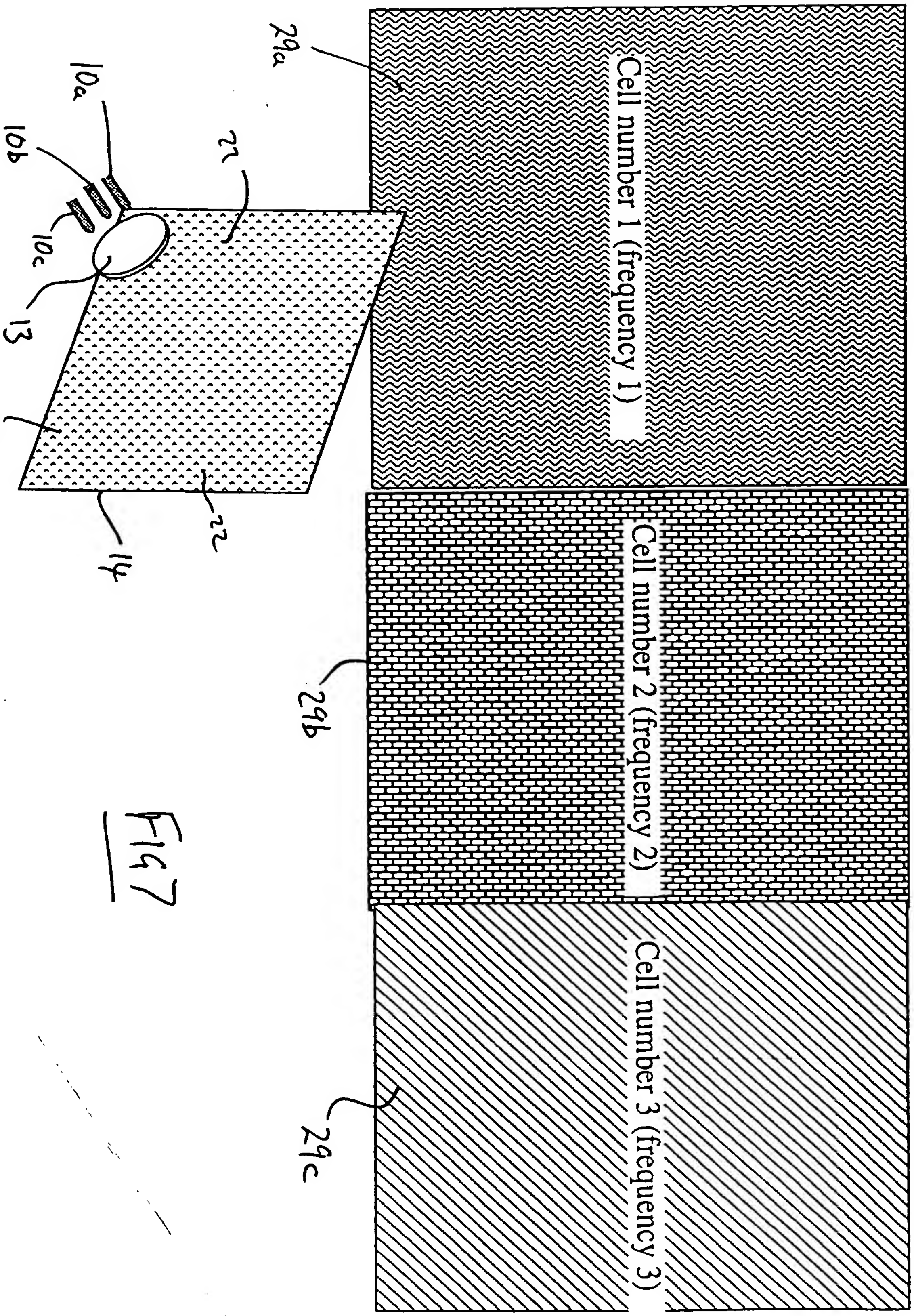

Cell number 1 (frequency 1)
Cell number 2 (frequency 2)
Cell number 3 (frequency 3)
29a
29b
29c
10a
10b
10c
13
22
22
22
14

FIG 7

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 92 30 6894

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int. Cl.5)
X	OPTICAL ENGINEERING vol. 31, no. 2, February 1992, BELLINGHAM US pages 245 - 250 , XP257531 W.C.SWEATT 'transforming a circular laser beam into a square or trapezoid-almost' * abstract; figure 3 * * page 245, left column, line 15 - line 21 * * page 245, right column, line 1 - line 32 * * page 248, right column, line 31 - line 53 *	1,2,4	G02B27/00 H04B10/10
Y		6,10-14	
X	EP-A-0 116 896 (HITACHI, LTD) * abstract; claims 1,2; figure 2 *	1,2,3,5	
A	WO-A-8 500 667 (NCR CORPORATION) * abstract *	4	
D,Y	APPLIED OPTICS vol. 30, no. 19, NEW YORK US pages 2685 - 2691 , XP216340 M.P.DAMES ET AL 'efficient optical elements to generate intensity weighted spot arrays: design and fabrication' * abstract * *introduction*	6	TECHNICAL FIELDS SEARCHED (Int. Cl.5) G02B F21V F21P G03H H04B
Y	US-A-4 504 122 (B.J.BARTHOLOMEW) * abstract; claim 1; figures 1,2 * * column 4, line 52 - column 5, line 6 *	10-14	

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	22 MARCH 1993	VAN DOREMALEN J.C.

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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